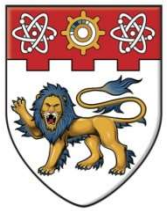

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Investigation of Arm Posture Mapping using Vibro-tactile Feedback

presented by

Tran Le Dung
Final Year Student
School of Mechanical and Aerospace Engineering

9th May 2012

Motivation & Objective

15m stroke patient

67% survive

Develop low-cost device for rehabilitation

Best feedback strategy for posture correction

http://2.bp.blogspot.com/69opYP6lmkU/TTVI_IZIRpzI/AAAAAAAAAEac/x8y2JdG_SGQ/s400/physiotherapy%2Bstroke%2Bold%2Bwoman.jpg

http://i1.ytimg.com/vi/tdFXIB3HLUQ/hqdefault.jpg

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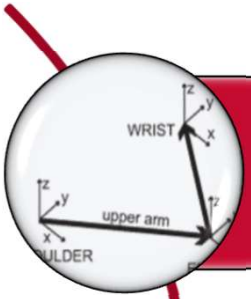
Overview of Presentation



Arm Posture Modeling & Measurement

Vibo-tactile for Posture Correction

Visuo-tactile for Posture Correction

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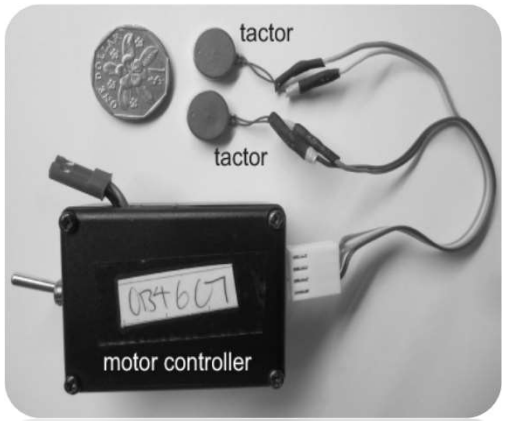
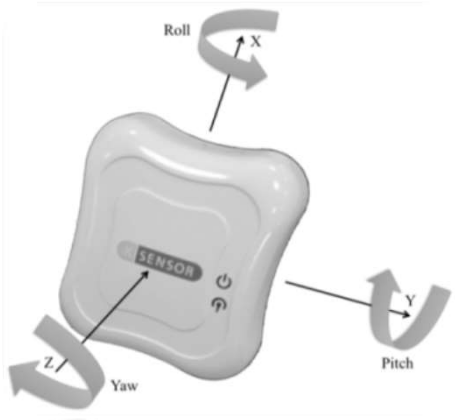
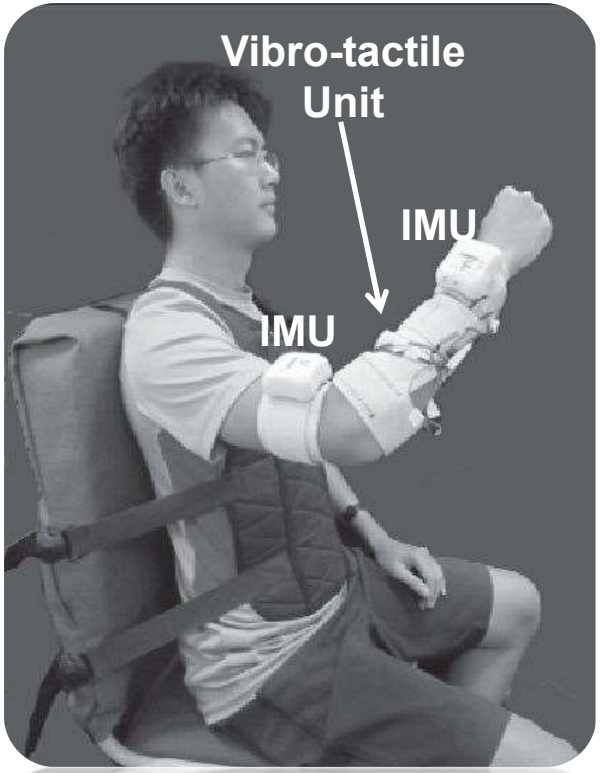
System Overview



Vibro-tactile Unit

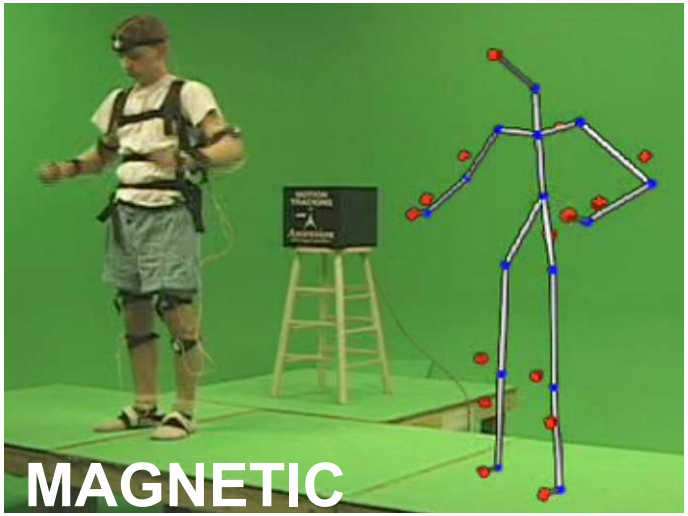


Inertial Motion Unit



Different ways of capturing motion

MECHANICAL SYSTEM

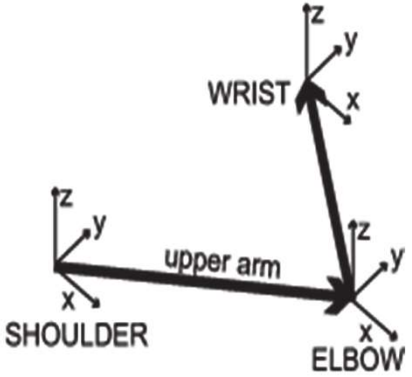


Arm Posture Modeling

Wrist Position

Elbow Position

Forearm Roll



ARM MODEL

Arm Posture Kinematics

IMU 1 - r_1, p_1, y_1

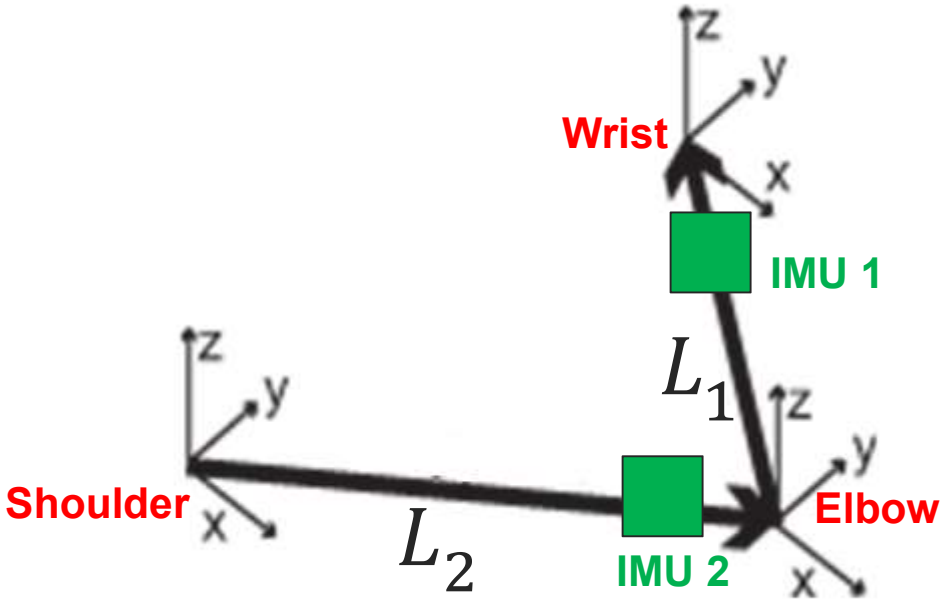
IMU 2 - r_2, p_2, y_2

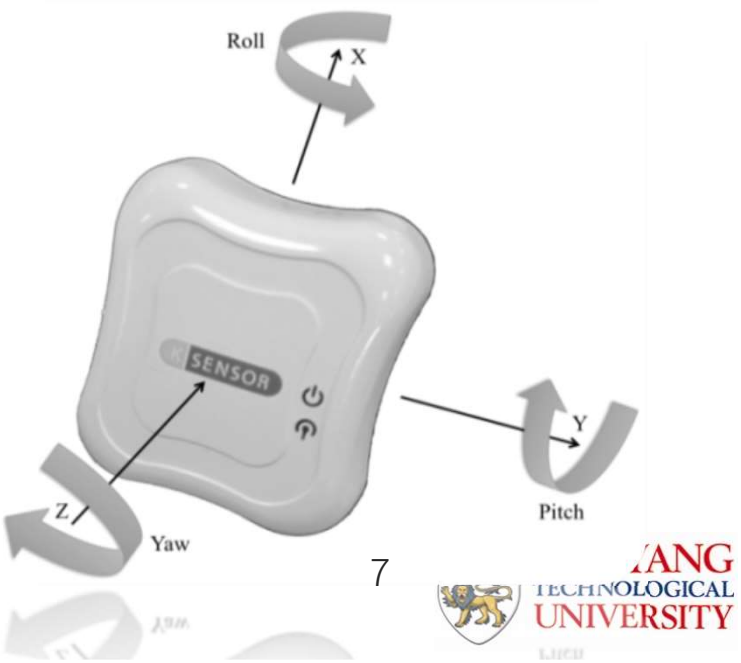
Arm Lengths - L_1, L_2

wrist - $f\,(r_1, p_1, y_1, r_2, p_2, y_2, L_1, L_2)$

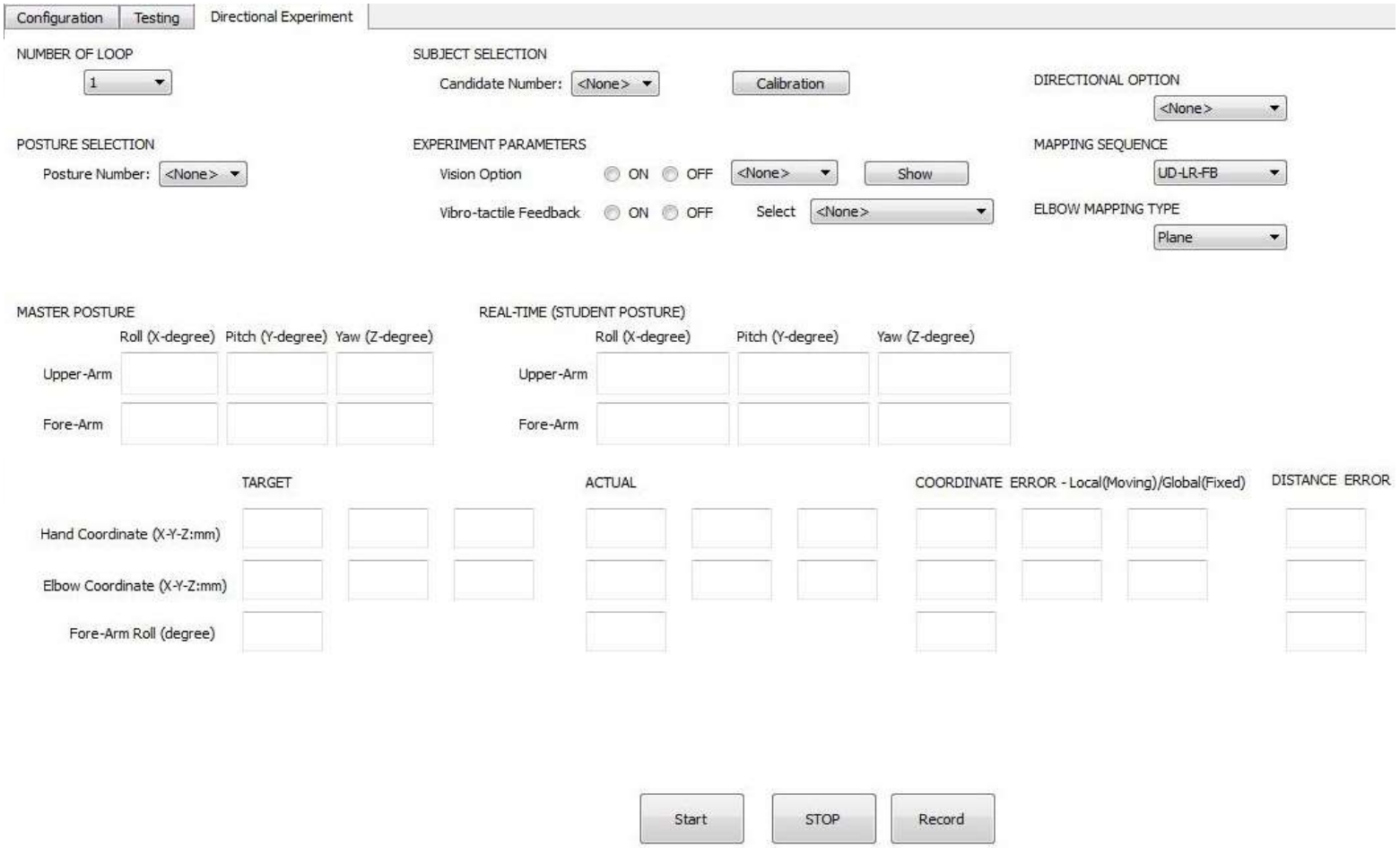
elbow - $f\,(r_2, p_2, y_2, L_2)$

forearm roll - r_1



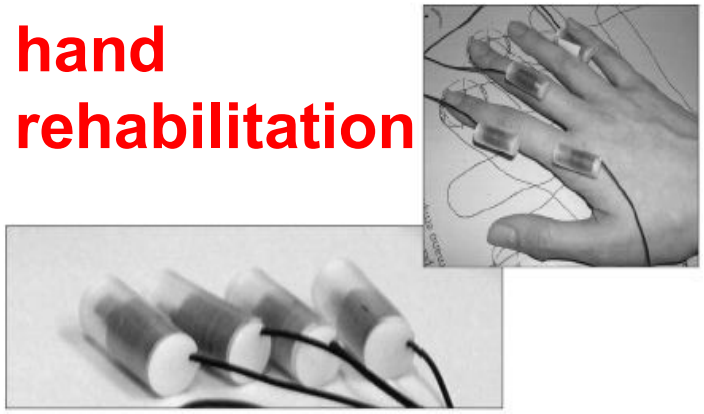


Design for GUI

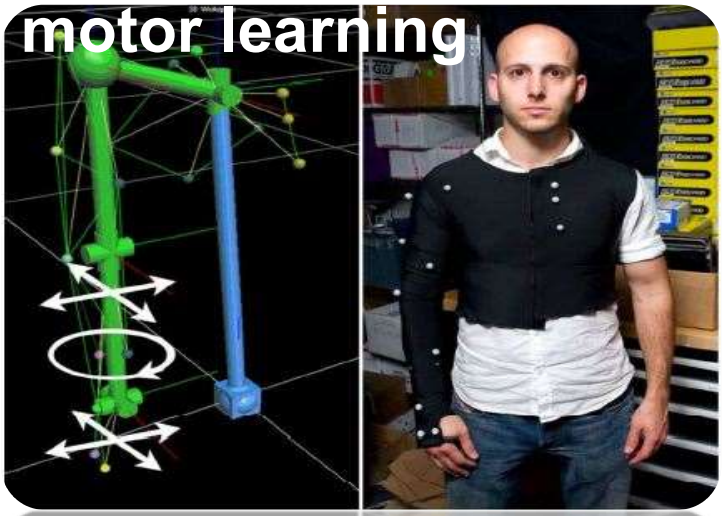


Vibro-tactile Feedback

hand rehabilitation

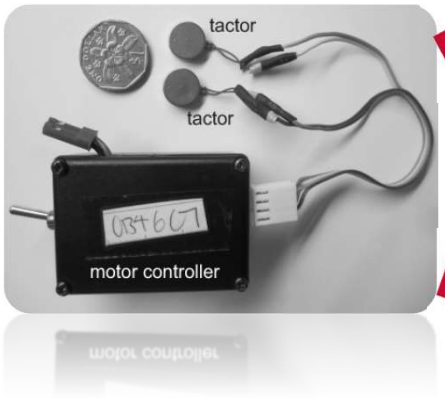


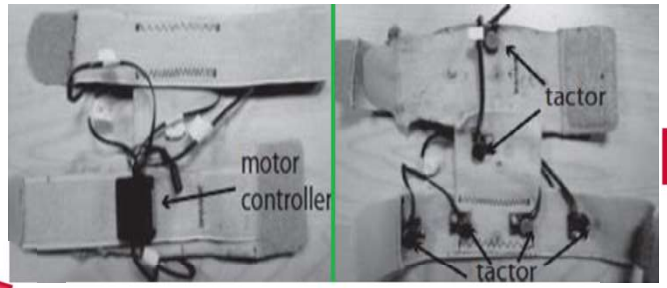
posture guidance



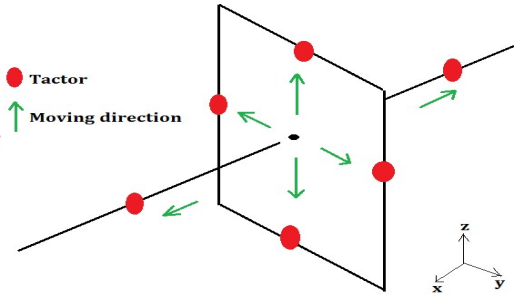
Vibro-tactile feedback for arm posture correction

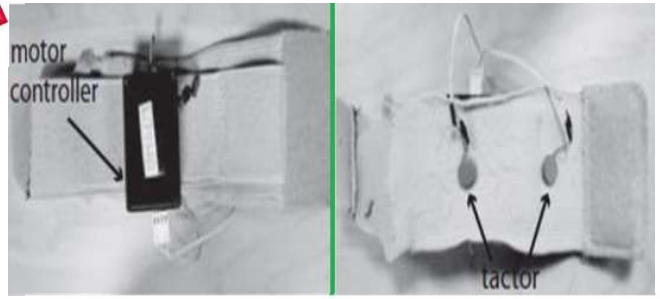
Vibro-tactile unit





Directional feedback



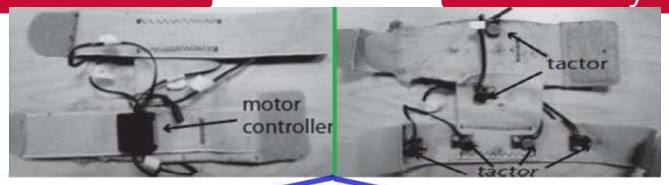


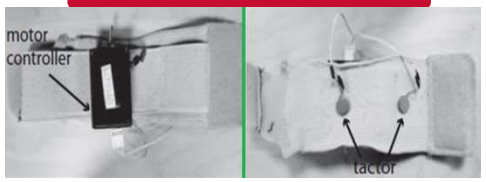
Matching error indicator (non-directional feedback)

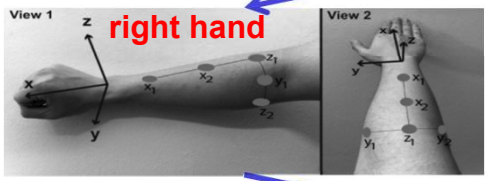
Direction-Moving Arm

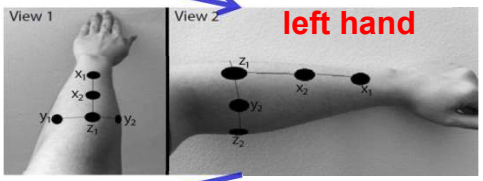
Direction-Stationary Arm

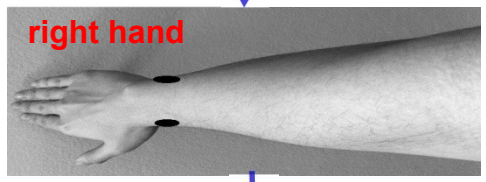
Matching Error Indicator

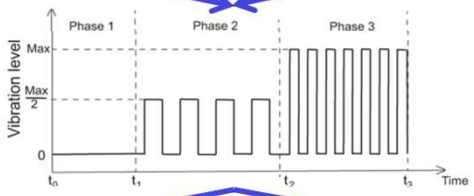


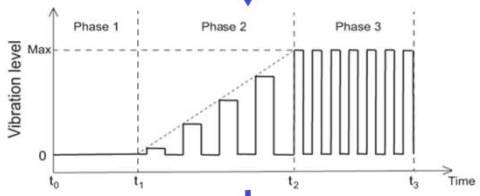




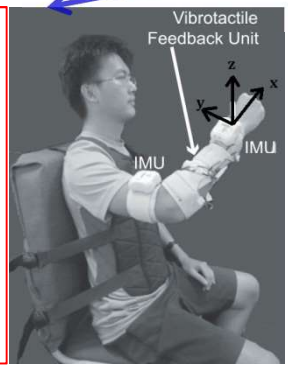




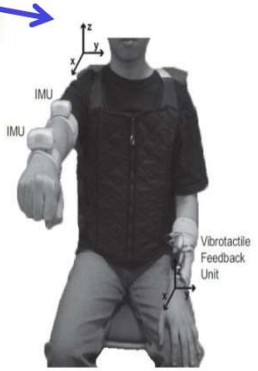




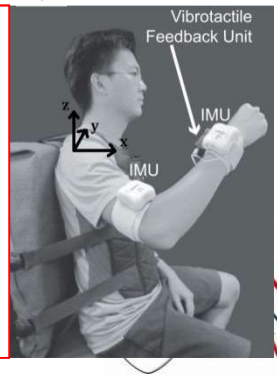
Local system at wrist



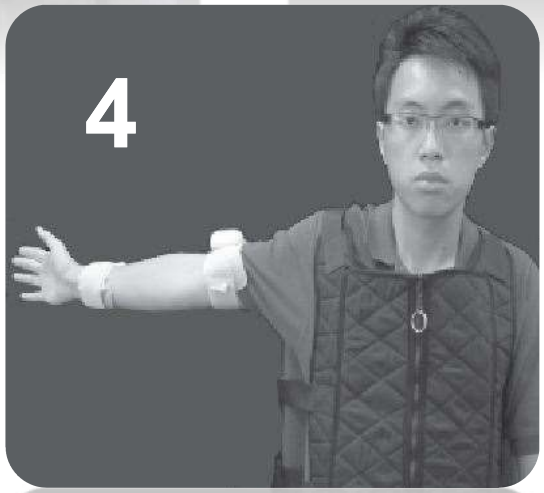
Global system at shoulder



Global system at shoulder



Experiments



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Directional Feedback

On Moving Arm

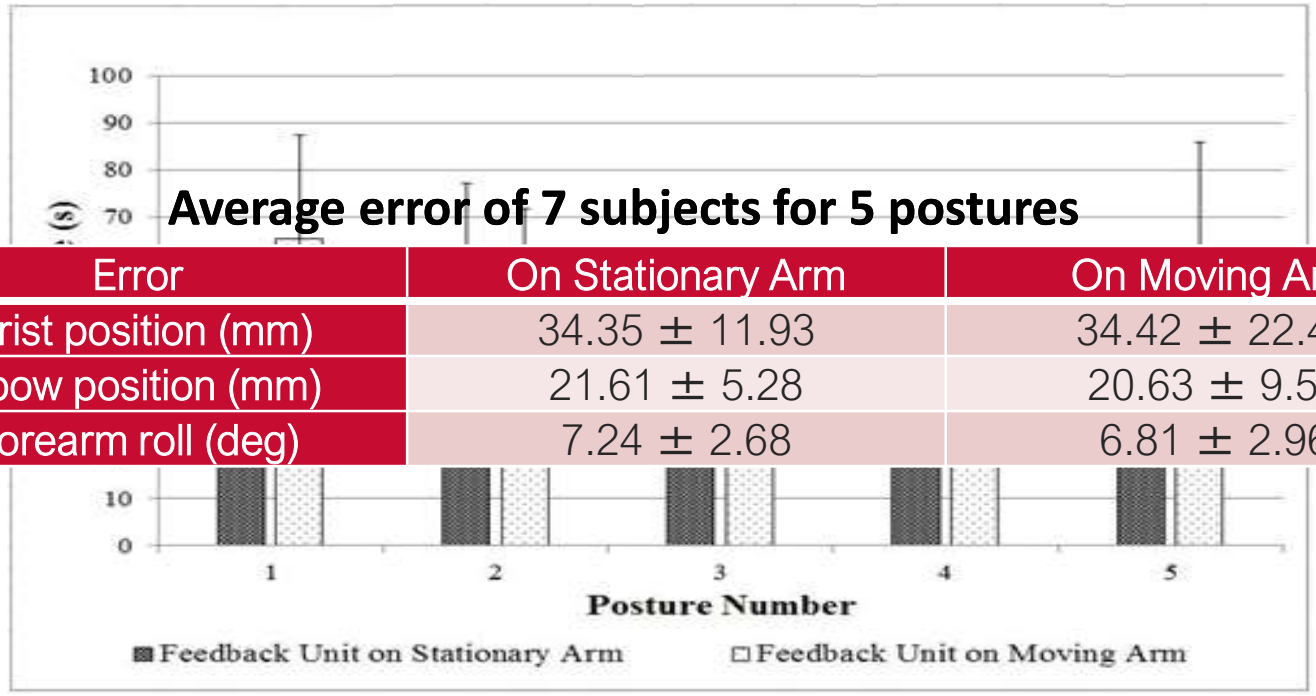
1m36s

On Stationary Arm

42s

Results

Directional feedback on stationary arm & moving arm



Average error of 7 subjects for 5 postures

Error	On Stationary Arm	On Moving Arm
Wrist position (mm)	34.35 ± 11.93	34.42 ± 22.46
Elbow position (mm)	21.61 ± 5.28	20.63 ± 9.53
Forearm roll (deg)	7.24 ± 2.68	6.81 ± 2.96

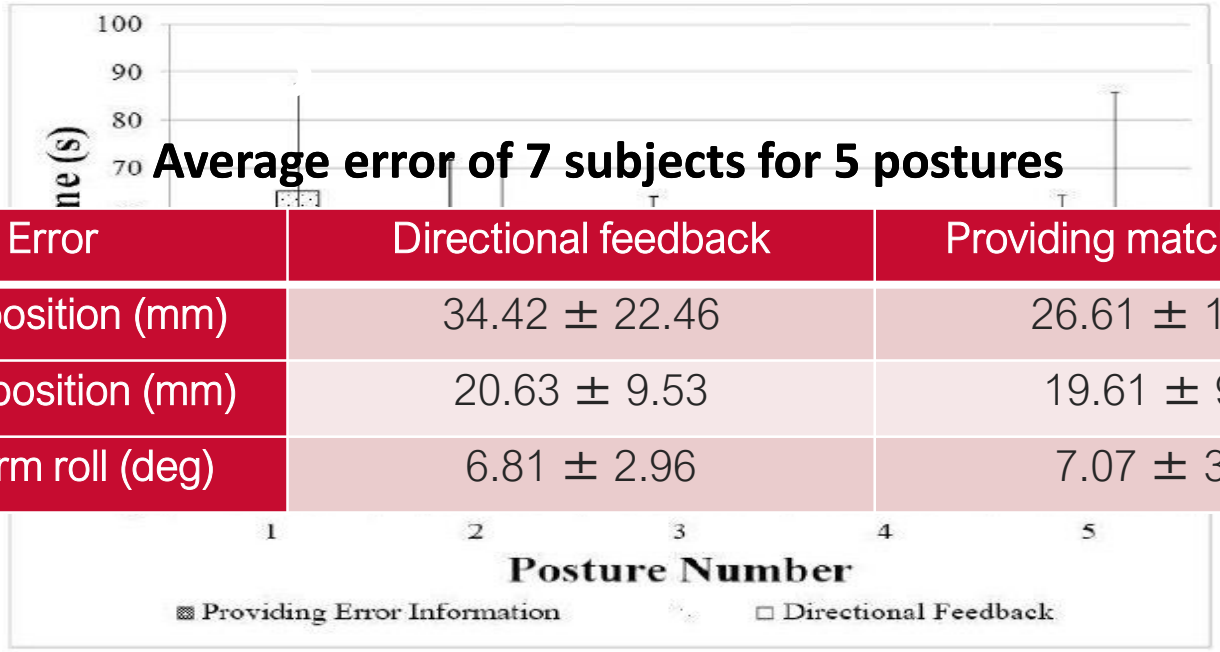
Feedback Strategy	Mapping Time (s)
On Stationary Arm	46.80 ± 13.23
On Moving Arm	52.68 ± 17.98

Providing Error Information (non-directional feedback)

12s

Results

The use of tactors as direction & matching error indicators

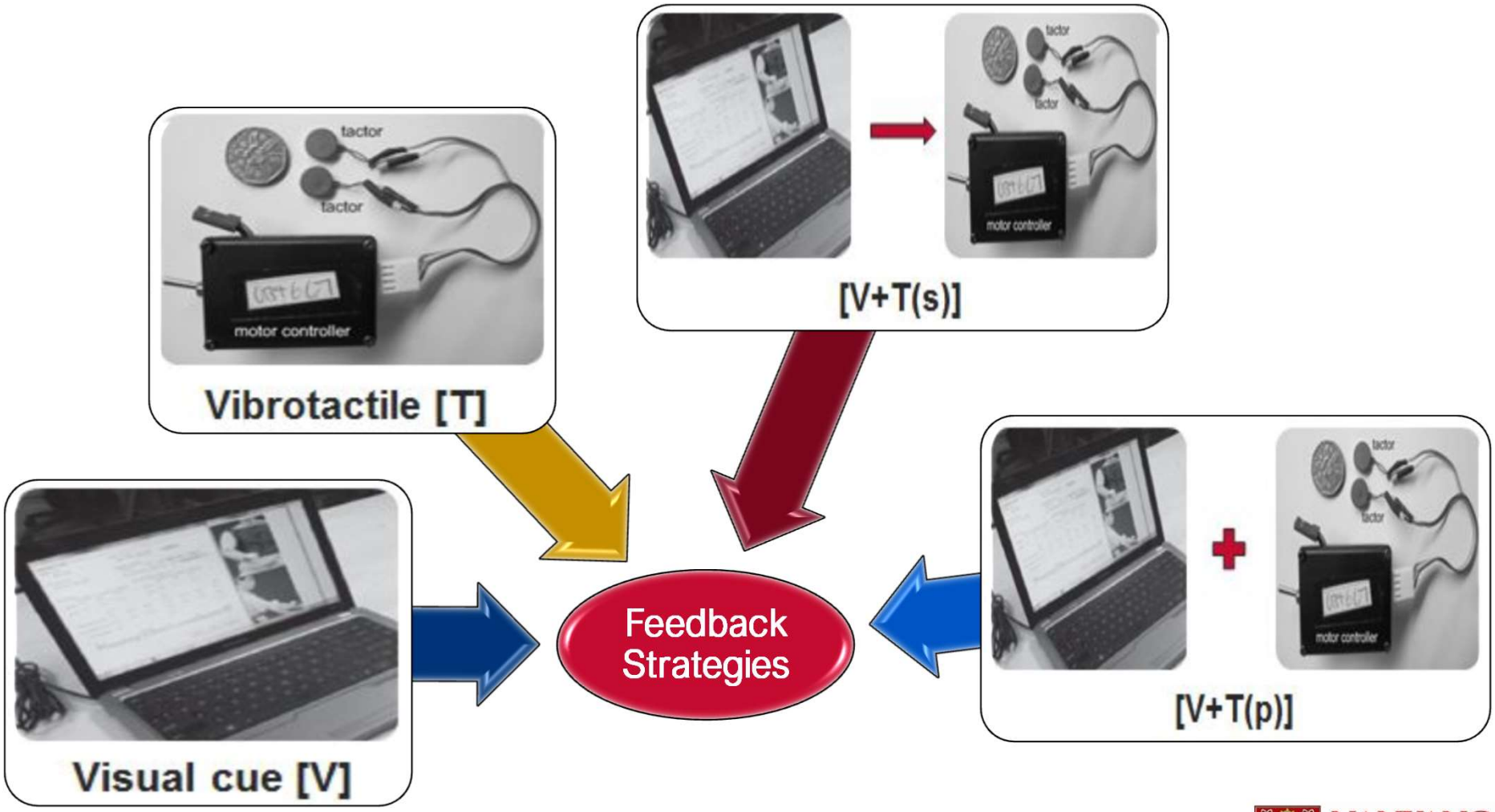


Average error of 7 subjects for 5 postures

Error	Directional feedback	Providing matching error
Wrist position (mm)	34.42 ± 22.46	26.61 ± 12.92
Elbow position (mm)	20.63 ± 9.53	19.61 ± 9.56
Forearm roll (deg)	6.81 ± 2.96	7.07 ± 3.05

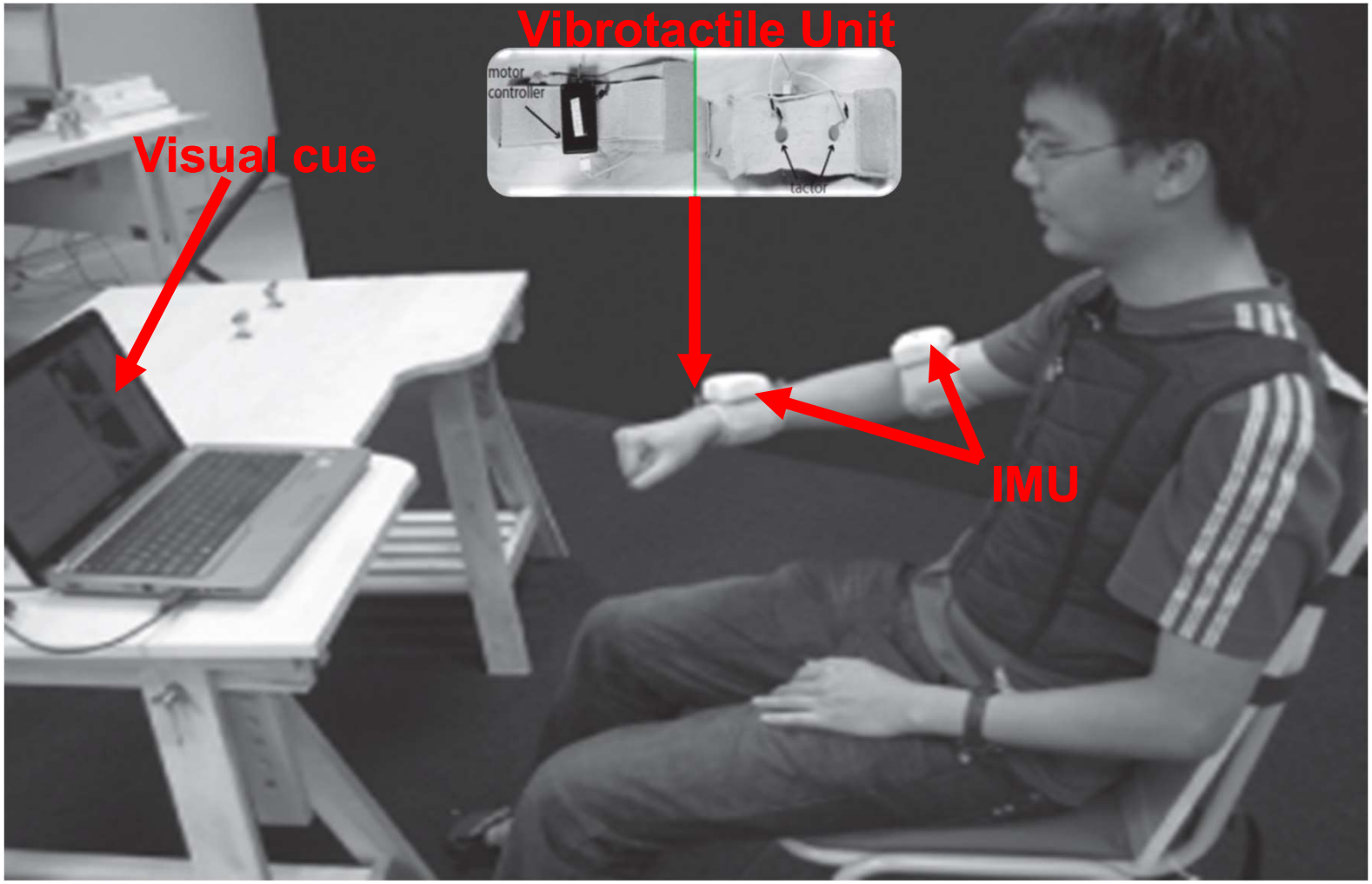
Feedback Strategy	Mapping Time (s)
Directional feedback	52.68 ± 17.98
Providing matching error	36.82 ± 19.37

Combination of Visual cue & Vibro-tactile Feedback



Experiments

Experiment Setup



Subject is trapped into chair

Video Demonstration

V+T(s) **V+T(p)** **T**

21s **30s** **41s**

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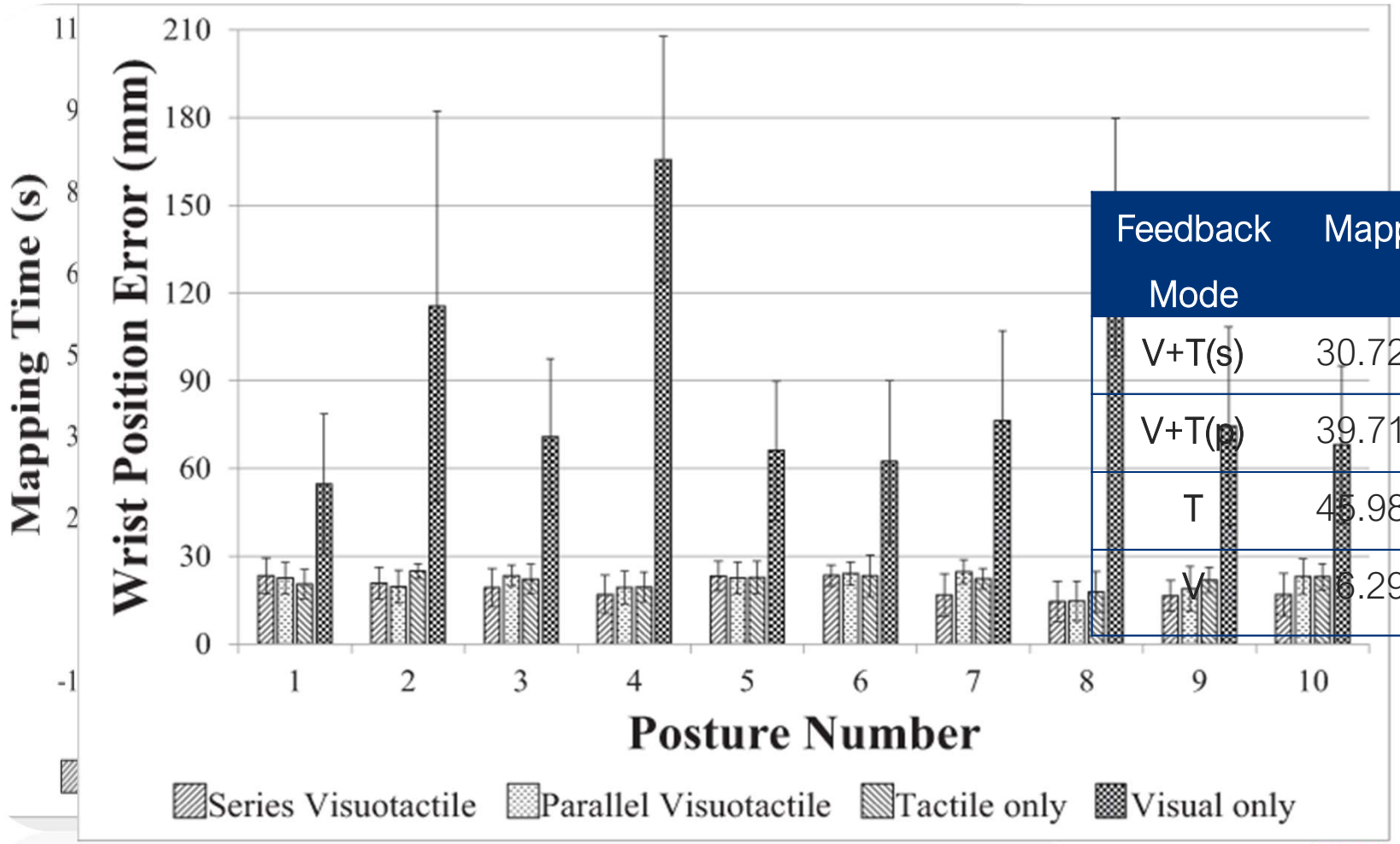
Results



Feedback Mode	Mapping Time (s)
V+T(s)	30.72 ± 12.53
V+T(p)	39.71 ± 19.82
T	45.98 ± 17.00
V	6.29 ± 4.65

Conclusion

Arm Posture Modeling & Measurement

- Arm kinematics
- GUI

Vibo-tactile for Posture Correction

- Direction on Stationary arm
- Matching error indicator

Visuo-tactile for Posture Correction

- Series visuotactile mode

Future Work

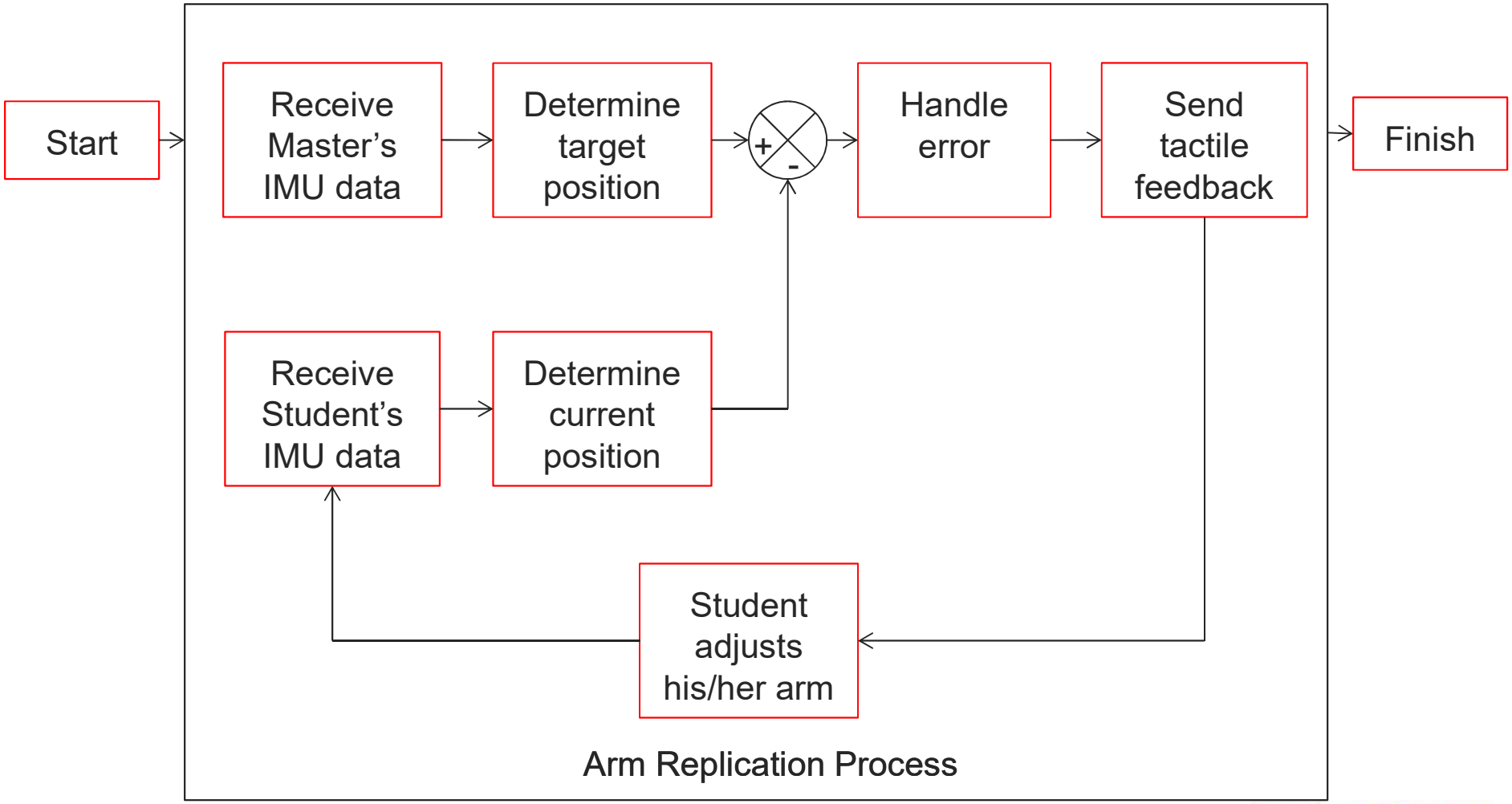
- Combine active visual + audio + vibro-tactile feedback
- Compare direction & matching error indicators when adding vision
- Design rehab modules

Thank you!

Email: tran0055@e.ntu.edu.sg

APPENDICES

Software - System Overview



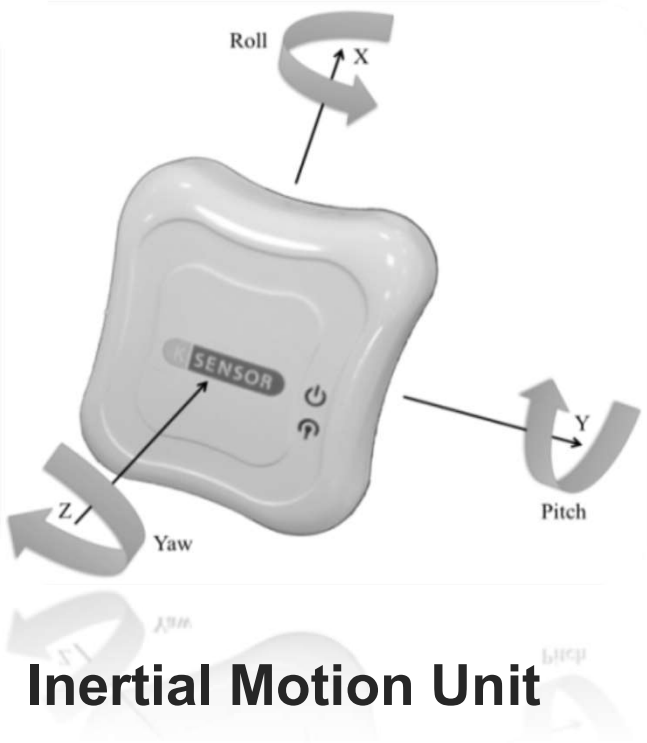
IMU Measurements

IMU packs 9 sensors (3 accelerometers, 3 angular rate gyros, 3 magnetometers)

$$\varphi_{gyro} = \int_{t_i}^{t_f} \omega_x \, dt$$
$$\rho_{gyro} = \int_{t_i}^{t_f} \omega_y \, dt$$
$$\theta_{gyro} = \int_{t_i}^{t_f} \omega_z \, dt$$

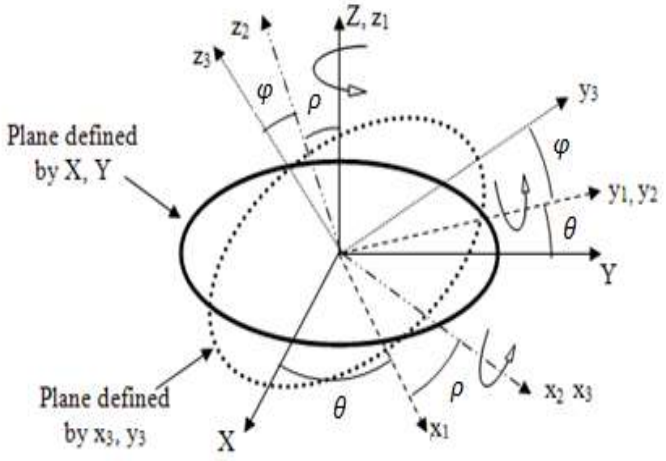
Given the angular value at $(t-1)$ and Δt, the numerical approximation becomes

$$\varphi_{gyro}(t) = \varphi_{gyro}(t-1) + \omega_x \, \Delta t$$
$$\rho_{gyro}(t) = \rho_{gyro}(t-1) + \omega_y \, \Delta t$$
$$\theta_{gyro}(t) = \theta_{gyro}(t-1) + \omega_z \, \Delta t$$



Inertial Motion Unit

Kinematic Formulation (1)



$$\begin{Bmatrix} x_1 \\ y_1 \\ z_1 \end{Bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}; \text{Yaw Rotation} \quad (1)$$

$$\begin{Bmatrix} x_2 \\ y_2 \\ z_2 \end{Bmatrix} = \begin{bmatrix} \cos\rho & 0 & -\sin\rho \\ 0 & 1 & 0 \\ \sin\rho & 0 & \cos\rho \end{bmatrix} \begin{Bmatrix} x_1 \\ y_1 \\ z_1 \end{Bmatrix}; \text{Pitch Rotation} \quad (2)$$

$$\begin{Bmatrix} x_3 \\ y_3 \\ z_3 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{bmatrix} \begin{Bmatrix} x_2 \\ y_2 \\ z_2 \end{Bmatrix}; \text{Roll Rotation} \quad (3)$$

Catesian transformation

Kinematic Formulation (2)

Pitch - y axis

Roll - x axis

Yaw - z axis

$$R(\varphi,\rho,\theta) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \quad (4)$$

Where,

$$r_{11} = cos(\varphi)cos(\rho)$$

$$r_{12} = sin(\varphi)cos(\theta) + cos(\varphi)sin(\rho)sin(\theta)$$

$$r_{13} = sin(\varphi)cos(\theta) - cos(\varphi)sin(\rho)sin(\theta)$$

$$r_{21} = -sin(\varphi)cos(\rho)$$

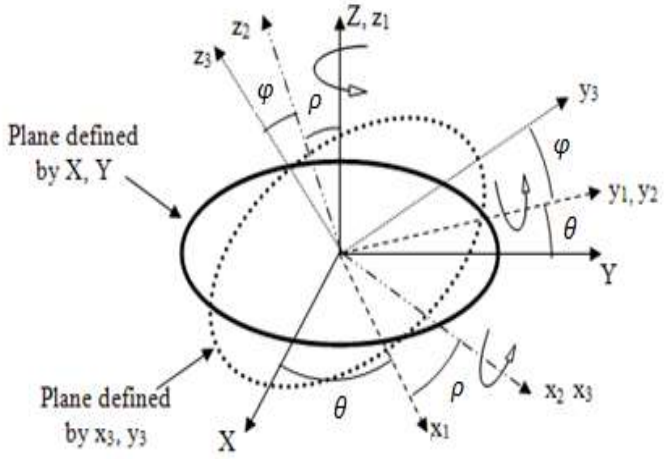
$$r_{22} = cos(\varphi)cos(\theta) - sin(\varphi)sin(\rho)sin(\theta)$$

$$r_{23} = r_{22} = cos(\varphi)cos(\theta) + sin(\varphi)sin(\rho)cos(\theta)$$

$$r_{31} = sin(\rho)$$

$$r_{32} = -cos(\rho)sin(\theta)$$

$$r_{33} = cos(\rho)cos(\theta)$$

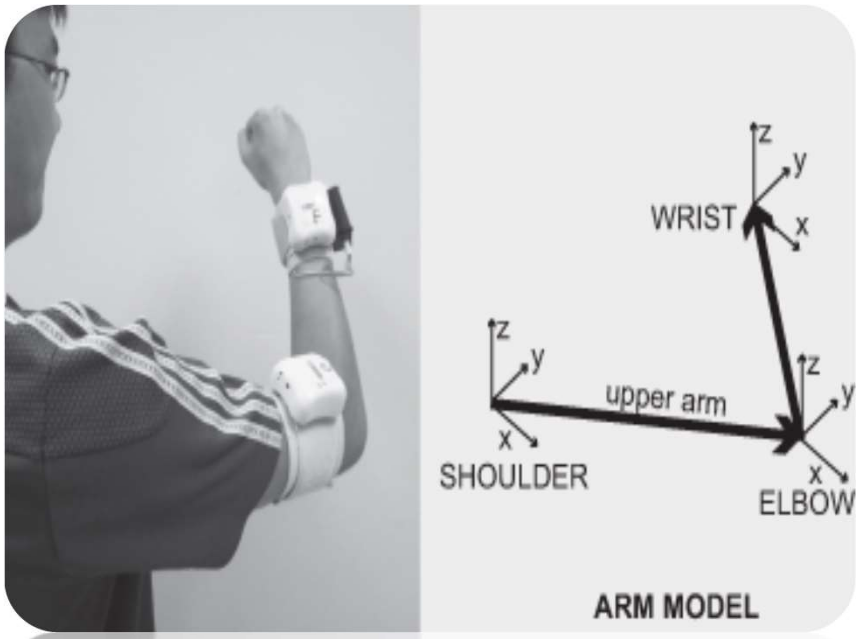


Kinematic Formulation (3)

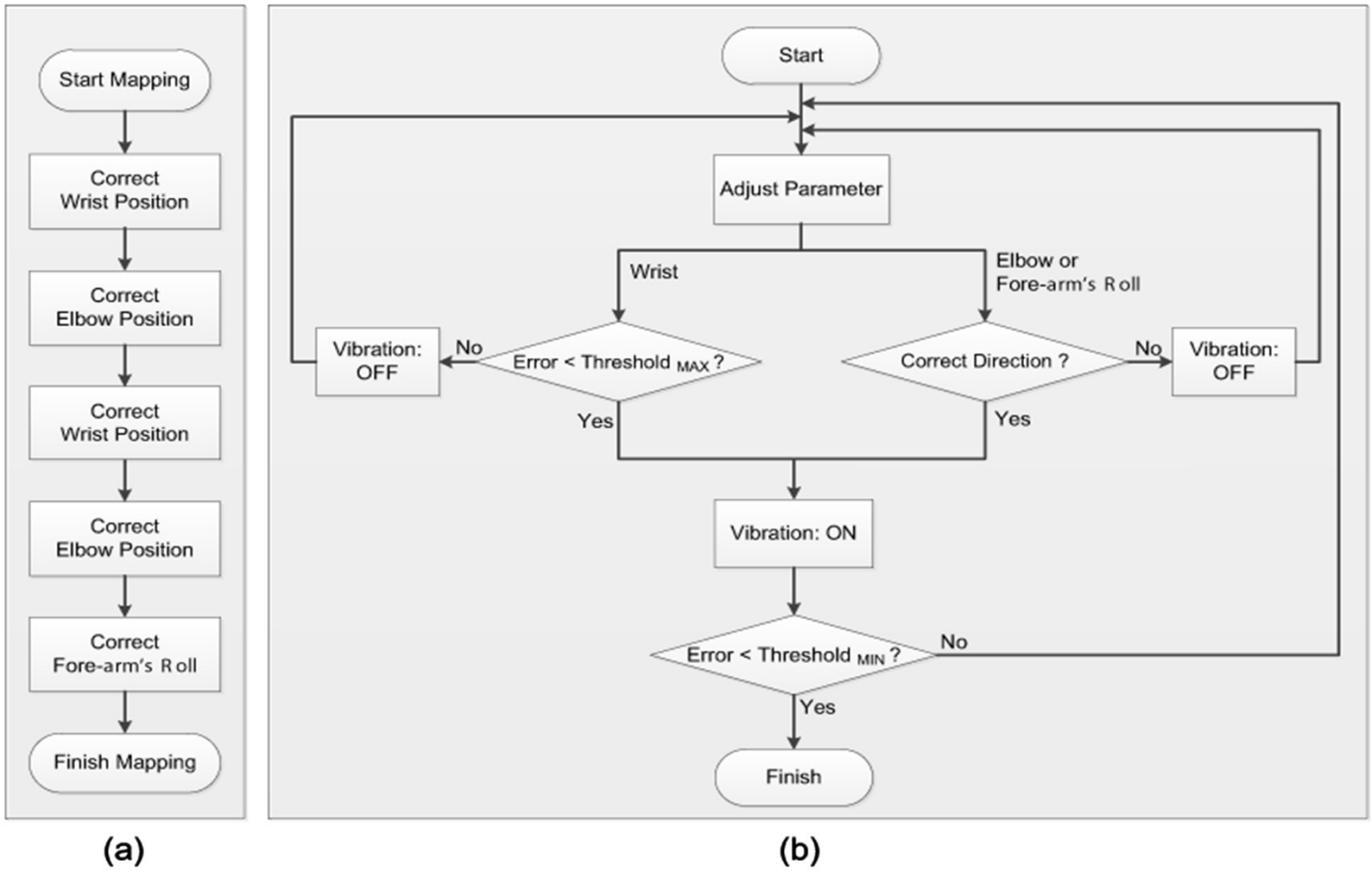
$$\begin{bmatrix} r_{11}^u & r_{12}^u & r_{13}^u & 0 \\ r_{21}^u & r_{22}^u & r_{23}^u & 0 \\ r_{31}^u & r_{32}^u & r_{33}^u & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} L_u \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} x_u \\ y_u \\ z_u \\ 1 \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} r_{11}^f & r_{12}^f & r_{13}^f & x_u \\ r_{21}^f & r_{22}^f & r_{23}^f & y_u \\ r_{31}^f & r_{32}^f & r_{33}^f & z_u \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} L_f \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} x_f \\ y_f \\ z_f \\ 1 \end{bmatrix} \quad (6)$$

where L_f is the forearm length and L_u is the upper arm length.



General Procedure



The mapping process

IMU Specification

IMU SPECIFICATIONS.

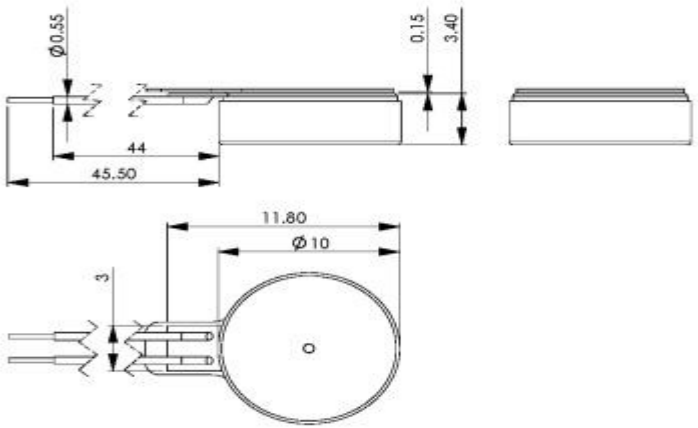
DOF	3 (roll, pitch, yaw)
Angular Range	360° (3 axes)
Accuracy	1° (yaw); 0.40° (pitch and roll) at 25°C
Angular Resolution	0.01° RMS
Update Rate	180Hz
Minimum Latency	2ms (RS-232)
Size	36.6 mm × 27.7 mm × 18.8mm
Power Supply	6V DC
Power Consumption	40 milliamps

Tactor Specification

Diameter (mm)	12
Thickness (mm)	3.4
Weight (g)	1.23
Standard Voltage (V)	3
Operating Voltage (V)	2.5 to 3.5
Power Supply	DC (battery)
Standard Speed (rpm)	12±3

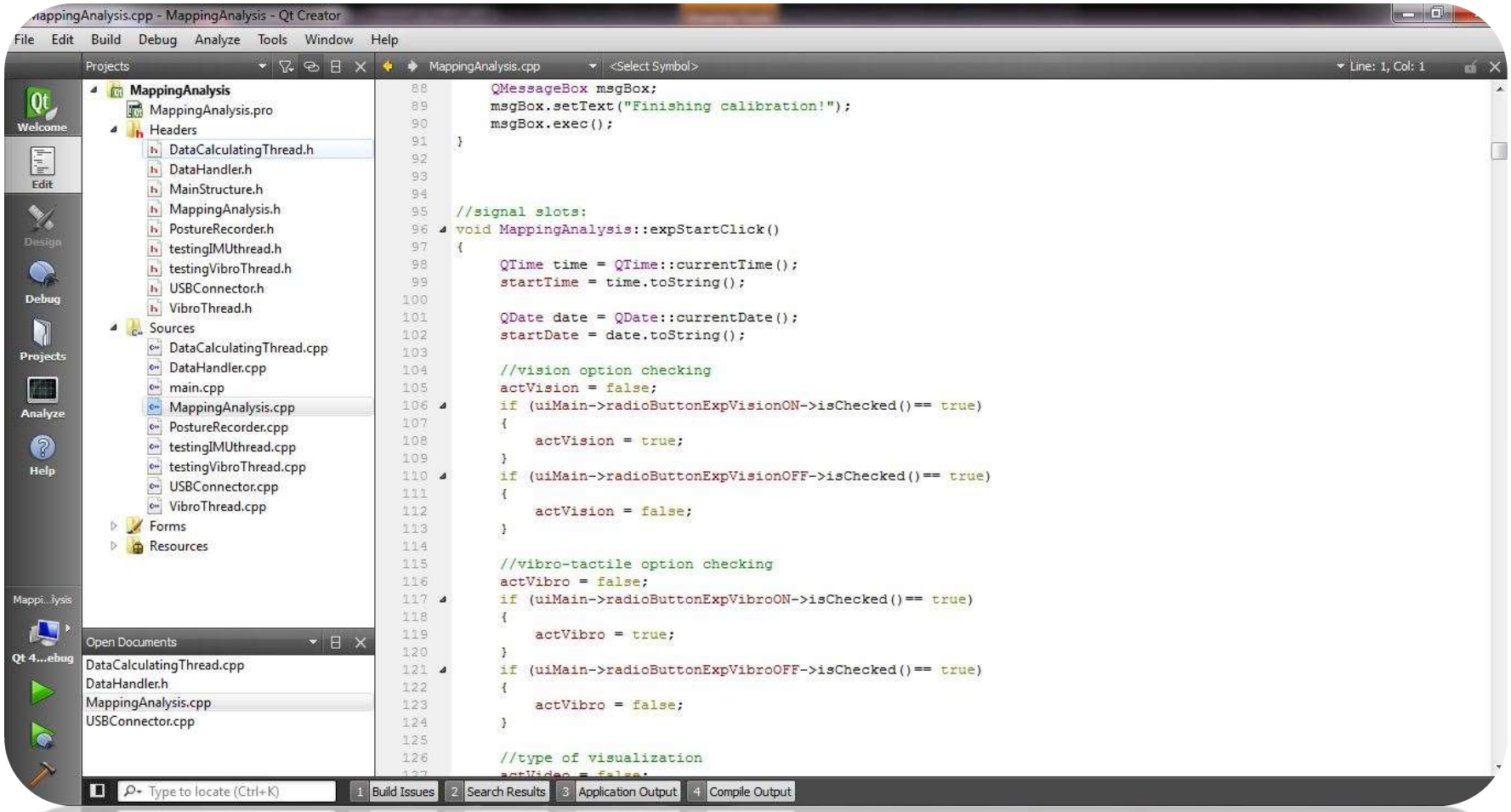
Specifications of VPM2

VPM2 tactor



Dimensions of VPM2

Capture of Program



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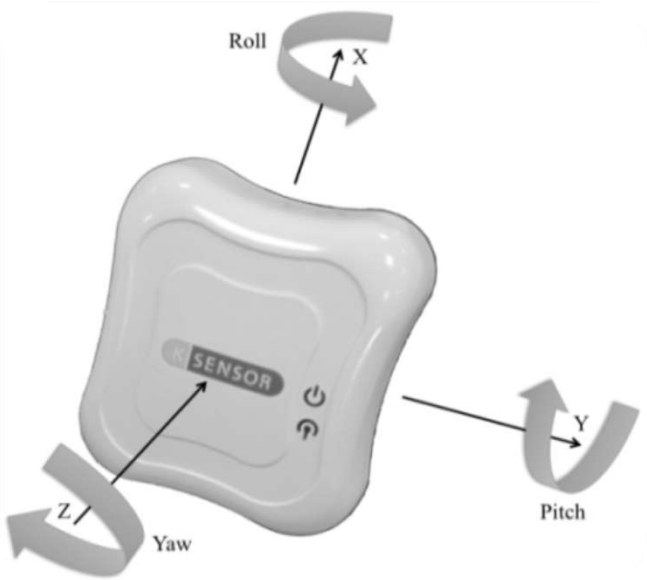
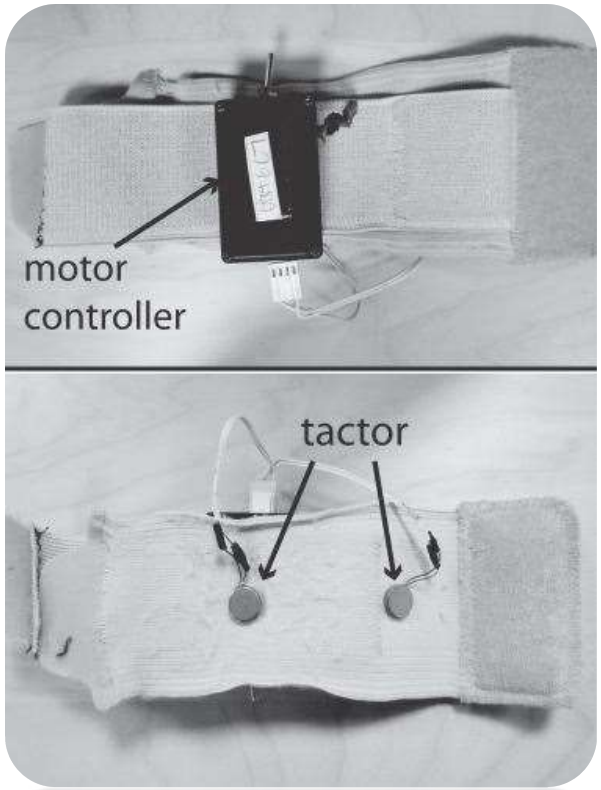
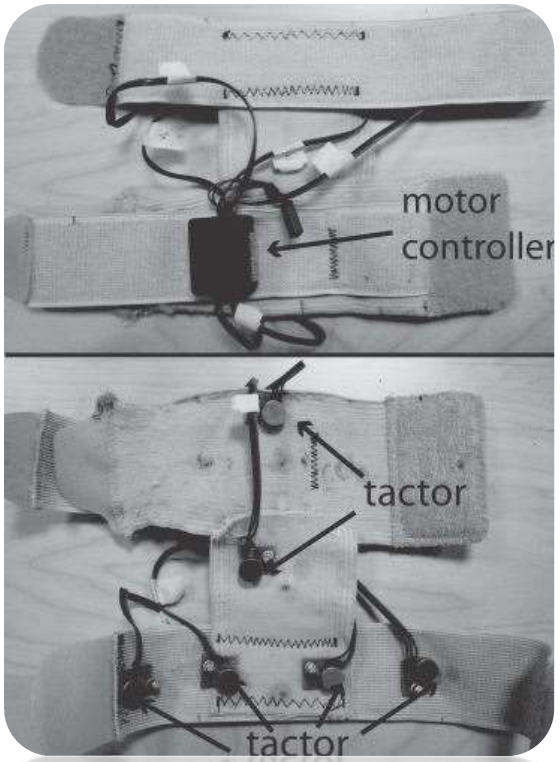
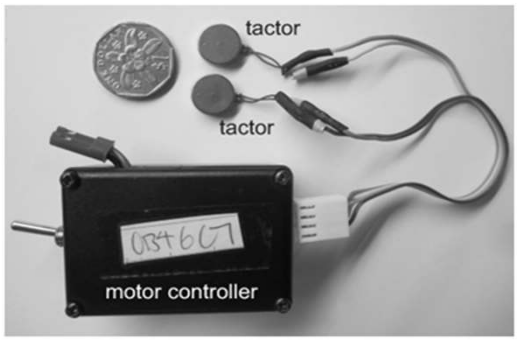
IMU device

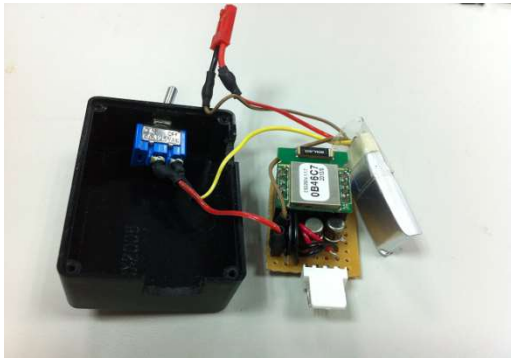


Vibrotactile Unit









Data

Direction and matching error indicators

Average mapping time of 7 subjects for 5 postures

Feedback Strategy	Mapping Time (s)
Matching error information	36.82 ± 19.37
Directional feedback	52.68 ± 17.98

Average error of 7 subjects for 5 postures

Error	Providing matching error	Directional feedback
Wrist position (mm)	26.61 ± 12.92	34.42 ± 22.46
Elbow position (mm)	19.61 ± 9.56	20.63 ± 9.53
Forearm roll (deg)	7.07 ± 3.05	6.81 ± 2.96

Data

Direction vibrotactile feedback on moving arm and stationary arm

Average mapping time of 7 subjects for 5 postures

Feedback Strategy	Mapping Time (s)
On Stationary Arm	46.80 ± 13.23
On Moving Arm	52.68 ± 17.98

Average error of 7 subjects for 5 postures

Error	On Stationary Arm	On Moving Arm
Wrist position (mm)	34.35 ± 11.93	34.42 ± 22.46
Elbow position (mm)	21.61 ± 5.28	20.63 ± 9.53
Forearm roll (deg)	7.24 ± 2.68	6.81 ± 2.96

Data

Combinations of Visual cue and Vibrotactile Feedback

Average mapping time of 10 subjects for 10 postures

Feedback Mode	Mapping Time (s)
V+T(s)	30.72 ± 12.53
V+T(p)	39.71 ± 19.82
T	45.98 ± 17.00
V	6.29 ± 4.65

Average error of 10 subjects for 10 postures

Error	V+T(s)	V+T(p)	T	V
Wrist position (mm)	19.18 ± 6.00	21.28 ± 5.41	21.82 ± 4.96	89.35 ± 34.31
Elbow position (mm)	17.81 ± 6.73	19.23 ± 6.35	17.85 ± 6.49	63.91 ± 26.55
Forearm roll (deg)	6.58 ± 3.27	6.99 ± 3.03	6.91 ± 2.69	22.22 ± 14.47

Threshold values

Directional and non-directional experiments

Parameter	Threshold Values
Wrist (Providing error information) : $R_{ND\_OUTER\_W}$	200 mm
Wrist (Providing error information) : $R_{ND\_INNER\_W}$	25 mm
Wrist (Direction) : $R_{D\_OUTER\_W}$	300 mm
Wrist (Direction) : $T_{D\_INNER\_W}$	15 mm
Elbow : R_{INNER_E}	25 mm
Forearm : $\Delta\varphi_f$	10°

Threshold values

Combinations of Visual cue and Vibrotactile Feedback

Parameter	Threshold Values
Wrist (1st loop): R_{OUTER_W}	150 mm
Wrist (1st loop): R_{INNER_W}	30 mm
Elbow (1st loop): R_{INNER_E}	30 mm
Wrist (2nd loop): R_{OUTER_W}	100 mm
Wrist (2nd loop): R_{INNER_W}	25 mm
Elbow (2nd loop): R_{INNER_E}	25 mm
Forearm: $\Delta\varphi_f$	10°